

Load-balancing System for the Distribution Network Using a Load-sharing Approach

Md. Humayun Kabir Khan*[‡] , Shams Ul Islam ** , Md. Ziaul Islam *** 

*Department of Electrical and Electronic Engineering, Faculty of Science and Engineering, City University, Dhaka, Bangladesh

** Department of Electrical and Electronic Engineering, Faculty of Science and Engineering, City University, Dhaka, Bangladesh

*** Department of Electrical and Electronic Engineering, Faculty of Science and Engineering, City University, Dhaka, Bangladesh

(humayun10eee@yahoo.com, shams.cityuniversity@gmail.com, ziaul18@yahoo.com)

[‡]Corresponding Author; Md. Humayun Kabir Khan, City University, Dhaka, Bangladesh,

Tel: +8801834300212, humayun10eee@yahoo.com

Received: 01.09.2024 Accepted: 27.09.2024

Abstract- To protect electrical loads that are at risk of damage, especially where voltage imbalance is a concern, protection systems are necessary. Unbalanced loads and line impedance cause the device to detect uneven voltage. Major three-phase electrical consumers include businesses, hotels, offices, retail centres, manufacturing, and educational institutions (phases R, Y, and B). When electrical installations are planned and installed by technicians (electrical experts), the load connected to the R, Y, and B phases is always intended to be balanced evenly. However, during operation, electricity is not always distributed evenly in each phase, leading to an unbalanced load between phases. This imbalance results in power losses. The aim of this study is to compare the unbalanced load current with the load current after balancing, to assess the effectiveness of three-phase electrical load balancing. The Arduino Uno is used in this system to process and provide data to Visual Basic (VB). The system also measures loads and electrical characteristics, which can be scheduled to offer a monitoring platform with a graphical user interface (GUI). This GUI may be used in a smart meter system and displays real-time power information to illustrate the amount of energy consumed, assisting the operator in problem-solving. It is hoped that this study will make interference identification and evaluation simpler.

Keywords: Load Balancing; GUI; Visual Basic.

1. Introduction

Single-phase AC, using a phase and neutral wire, powers household loads and small businesses. In contrast, three-phase AC is used for power generation, transmission, and distribution. A three-phase generator has fixed coils spaced 120 degrees apart, while a single-phase generator has a rotating coil. This results in three voltages that are 120° out of phase and are typically coloured red, yellow, and blue. Imbalances in three-phase systems can cause power fluctuations and neutral currents. This phase mismatch increases safety risks, reduces system efficiency, and can damage equipment. Real-time adjustments are needed to

prevent these issues. The term "load balancing approach" refers to this real-time regulating method. In other words, load balancing is the technique used to prevent situations when the electrical systems are overloaded or under loaded [1]. Intelligent systems, such as electrical power systems and distribution networks, are essential for the future. Modern technology can address issues like voltage and current imbalances and uneven load distribution across phases. These imbalances can cause voltage drops, transformer malfunctions, and increased energy losses, impacting electricity production and network efficiency. To mitigate these problems and manage rising maintenance costs, various solutions are available. These include redistributing

transformers, using Scott and Steinmetz transformers, connecting circuit breakers and capacitors, employing static VAR compensators (SVC), reconfiguring feeders, and phase swapping [2,3].

By opening and closing switches, network configurations can be adjusted at both the system and feeder levels through phase swapping and feeder reconfiguration procedures [4, 5]. Phase swapping involves redistributing loads across the feeder's three phases to achieve balance. Although phase swapping is generally more effective, feeder reconfiguration involves relocating houses connected to the feeder by opening and closing switches at the beginning and end of each feeder. This method aims to balance the feeders in the electrical grid [6, 3]. Researchers have explored various techniques for feeder reconfiguration, including the Heuristic Search Approach [7], Genetic Algorithms (GA) [8], Fuzzy Logic [9], and combinations of Fuzzy Logic with Newton-Raphson methods [10].

This research introduces a new approach to re-establishing balance in the electrical distribution network. It involves a redistribution and balancing device at the transformer and smart meters in homes that switch between phases using various contractors. Some homes have three-phase loads, while others have single-phase loads. Balancing is achieved by switching phases in specific residences according to the heuristic search method. Imbalances in current or voltage arise from magnitude or phase shifts. Increased power consumption and imbalance occur over time [11]. Causes of unbalanced loads include increased loads on one phase, manual switching of single-phase houses to other phases, unequal distribution of single-phase loads on three-phase lines, unequal impedances in power transmission or distribution, and unbalanced windings in three-phase devices like induction motors [12,13].

The "voltage or current imbalance index" for distribution networks and residences can be determined by calculating the ratio between the negative and positive sequence components. According to the European Standard EN 50160 (1994), an imbalance ratio within 2% is acceptable [14]. This ratio is calculated based on the deviation of one phase from the mean of the three phases. Similarly, the "phasing unbalance index (PUI)" of current can be determined [15].

This study introduces a real-time, automated load balancing system at the household level, addressing gaps in previous approaches that focus on system-wide phase swapping or feeder reconfiguration. Using smart meters and Arduino-based control, the system dynamically switches single-phase loads between three-phase lines, ensuring precise load balancing and immediate response to imbalances. Unlike traditional methods that require manual intervention, this approach automates the process via relays, reducing human error and improving efficiency.

The integration of low-cost hardware components, such as Arduino microcontrollers, presents a cost-effective alternative to more expensive solutions like Scott and Steinmetz transformers or static VAR compensators (SVCs). Additionally, the use of a Visual Basic (VB) graphical user interface (GUI) for real-time monitoring and control

enhances user interaction, allowing for better visualization and management of load conditions.

A key contribution is the practical validation of the system through hardware simulation and a physical prototype, demonstrating the feasibility of the approach in real-world applications. By providing an affordable, automated, and scalable solution, this work offers significant improvements over existing techniques, particularly for smaller grids or regions with limited resources.

2. Methodology

In this paper, a three-phase load-balancing system has been explored. This automated load monitoring and control system comprises three components: a three-phase voltage monitoring unit, a load management decision device, and a load current monitoring unit. The Arduino Uno, programmed in C++, will connect to a personal computer via the RS232 interface. VB is used for GUI interaction in this proposed system. Phase voltage measurements for R, Y, and B are taken using three potential transformers connected to voltage divider circuits and the Arduino's analog pins. The three distinct phase currents of the low-tension distribution feeder network are measured using three current transformers, whose outputs are connected to additional Arduino analog input ports. The voltage and current sensor outputs will provide the six analog inputs for the Arduino Uno. After processing these inputs, the Arduino Uno produces the necessary control signals. All input parameters are displayed on a PC using a GUI system developed with VB.

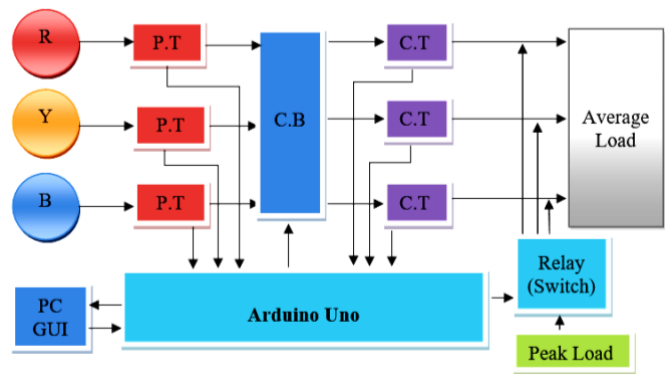


Fig. 1. Block diagram of the proposed system.

2.1. Smart Load Management

A smart load comprises a fixed load that remains constant and an adjustable load that is controlled over time. This research uses both high and light industrial loads to simulate industrial scenarios. Heavy industrial loads, such as those involving conveyor belts and motors, are more sensitive to energy rates compared to lighter loads. When an industrial load participates in Demand Response (DR), the daily total load must remain constant to meet the assigned output volume [16, 17]. However, the economic advantage must also be ensured. This study proposes a smart load management algorithm for DR that accounts for fluctuating labour and power prices. Typically, the cost of a single

product is divided into four categories: raw material costs, labour costs, power costs, and miscellaneous expenses (e.g., transportation and external effects). Raw material costs are further divided into direct and indirect expenses, and for simplicity, it is assumed that these costs remain constant over time. Therefore, the factors influencing DR for industrial loads are primarily labour costs and energy prices during each time period. Data is acquired in this study and displayed in the VB GUI, with features for controlling the setup directly from the GUI, as illustrated in Fig. 2.

house load is connected to the phase with the least load among the three phases, allowing for load balancing as needed. The display shows fluctuations in parameters such as voltage, current, and the state of the connected phases at any given time.

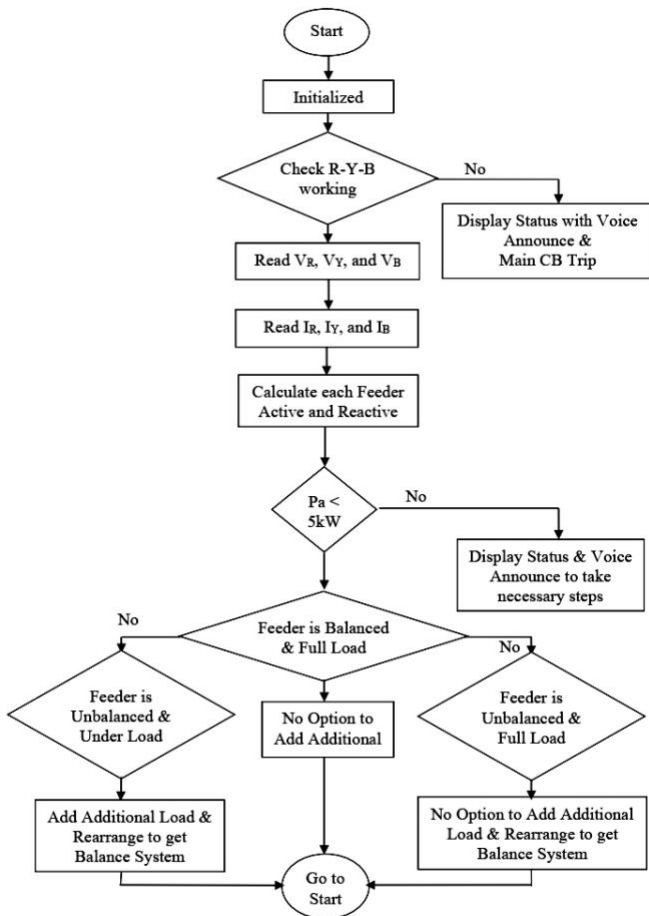
The circuit configuration of power supply unit has been shown in Fig. 4. The positive voltage regulator IC 7805 and 7812 are installed in order to give a constant +5V and +12V dc, respectively, so that the microcontroller operates on +5V and the relay and relay driver IC operate on +12V dc supply. The input 220V AC supply is converted into a 12-16V DC supply with the aid of a full wave bridge rectifier, and it is filtered through a capacitor to get a pure DC supply.

3.1. Hardware

This hardware is a prototype and experimental design of a three-phase distribution system, as shown in Fig. 5 and Fig. 6. This configuration is particularly useful for addressing three-phase imbalances near distribution transformers. The issue arises because the LV side of the current radial distribution network is connected to a single full home load. Using this hardware can stabilize the power system and enhance the efficiency of the distribution transformer by shifting the single-phase load to the least-loaded phases of the three-phase LV network. Before finalizing the Arduino Uno programming and component assembly, the design and code were repeatedly tested using the VB real-time simulator to ensure functionality. Initially, the circuit was breadboarded for effective design manipulation and tested for reliability. The components were then assembled and soldered onto a Vero board, which was mounted on a wooden board.

3.2. Load Management System (EMS)

In the management software built on the Visual Basic (VB). The management program's applications include real-time monitoring, scheduling each component, and evaluating the feeder condition and operating mode, as seen in Fig. 7 and Fig. 8. The screen of the GUI created in this proposed system at different stages of the operation is shown in Fig. 7. While the coloured circles show the three phases of the feeder/incoming lines, it also shows the voltage, current, real power, and reactive power of the individual phase.



3. Hardware Implementation

The design of the proposed hardware, shown in Fig. 3, has been created using Proteus software. The automated three-phase load balancing system was initially implemented in Proteus simulation, and these findings were used to construct the hardware for the proposed system. The hardware is divided into three main circuits (current sensing, relay operating, and controller circuits) each comprising the electrical components depicted in Fig. 3 and displays the complete simulation of the autonomous three-phase load balancing system, including the electrical symbols and names of each component. The simulation is conducted using the Proteus program. It employs three-phase input and produces a single-phase output. The single-phase complete

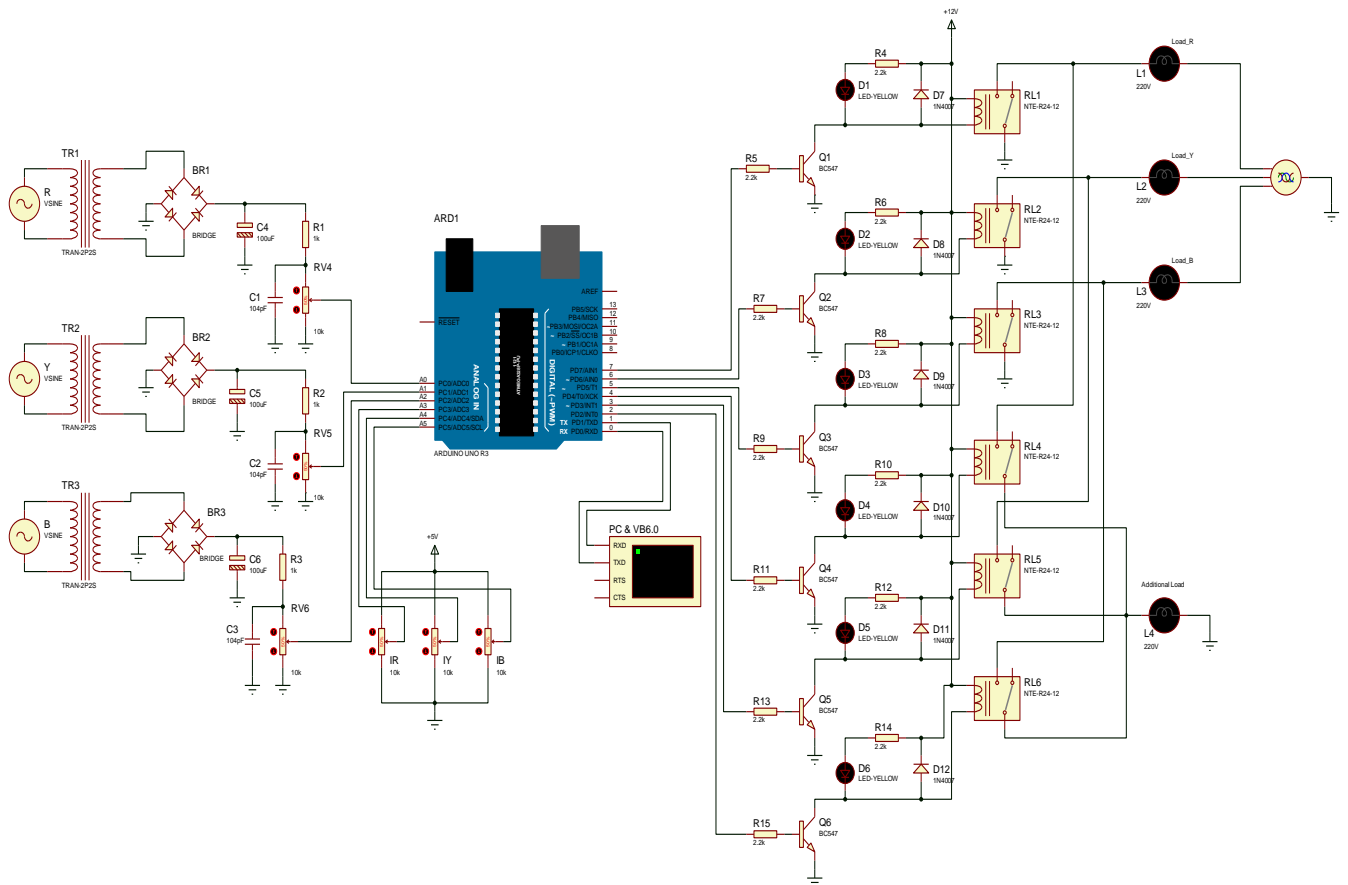


Fig. 3. Circuit diagram of proposed system.

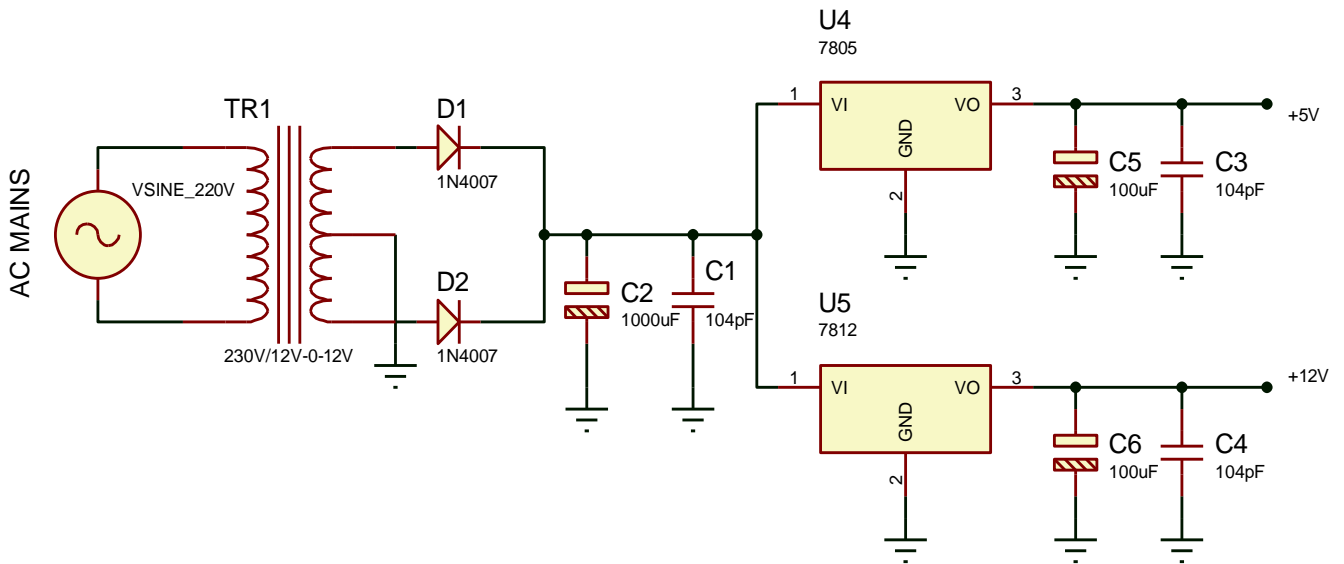


Fig. 4. Power supply unit.

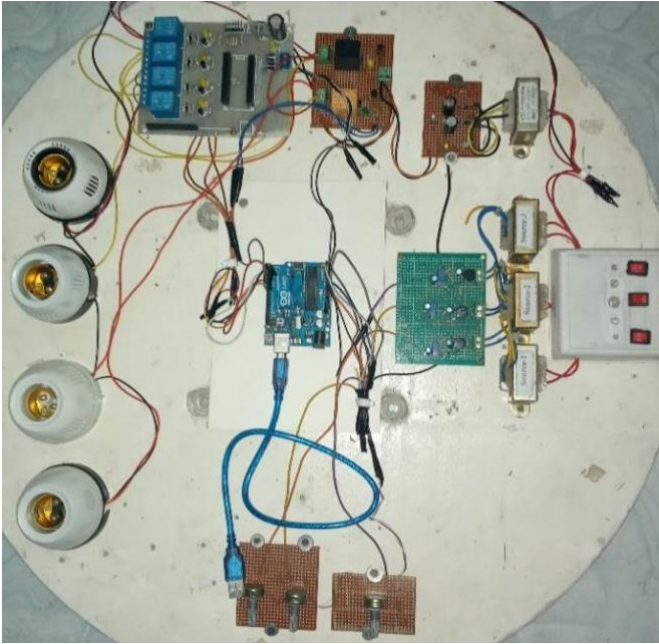


Fig. 5. Complete hardware setup for load balancing system.

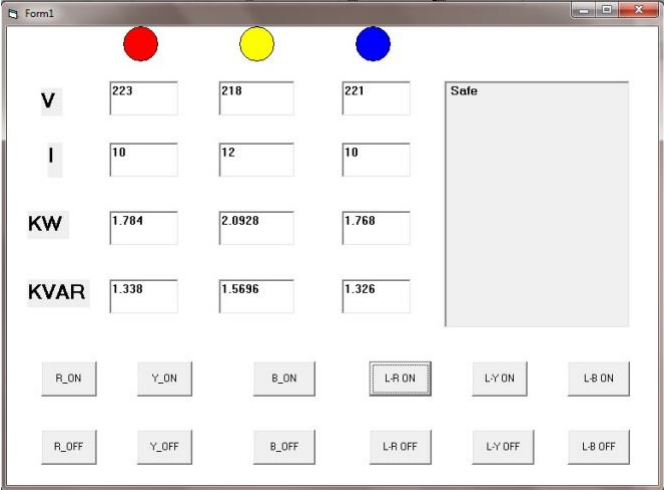


Fig. 7. Designed GUI for the proposed system.

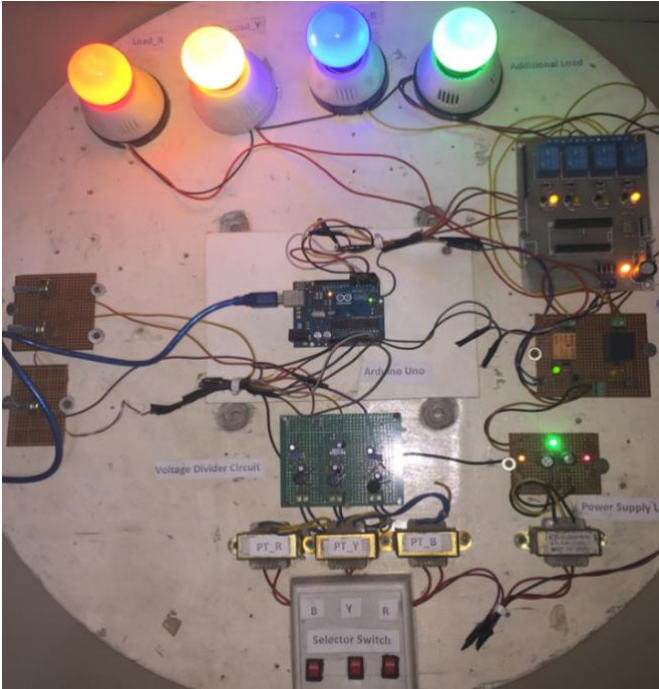


Fig. 6. Complete hardware setup (prototype) in operation.

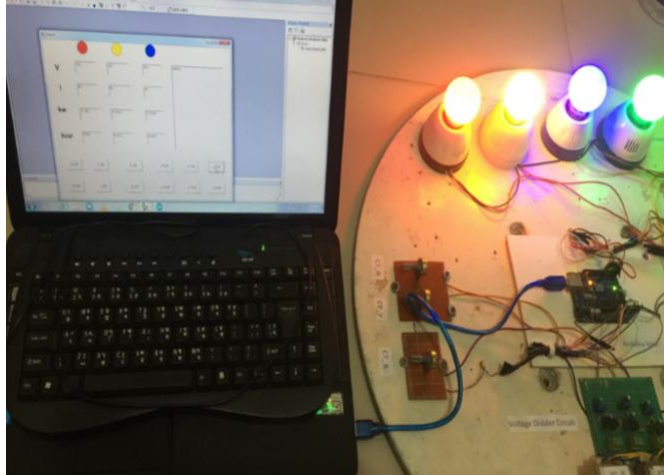


Fig. 8. Designed GUI and hardware in operation.

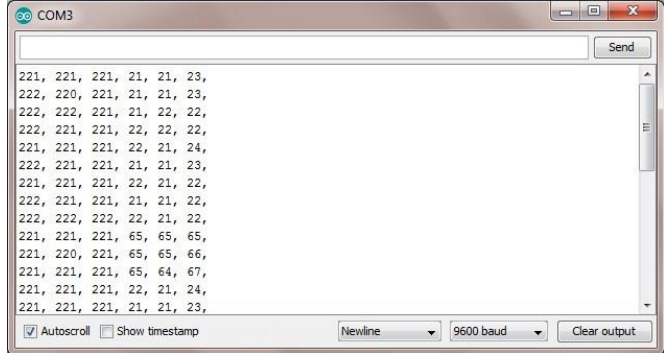


Fig. 9. CSV data from Arduino through RS232.

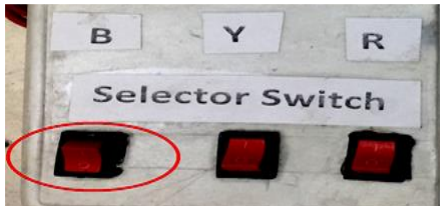
4. Results

While the loads on the three-phase input line vary, the single-phase output load is maintained constant. Relays connect the entire house load to the phase that is least burdened. In each phase, the variable loads range from 0 to 1000W. The display's phase switching between the three phases of the incoming load was continuously monitored,

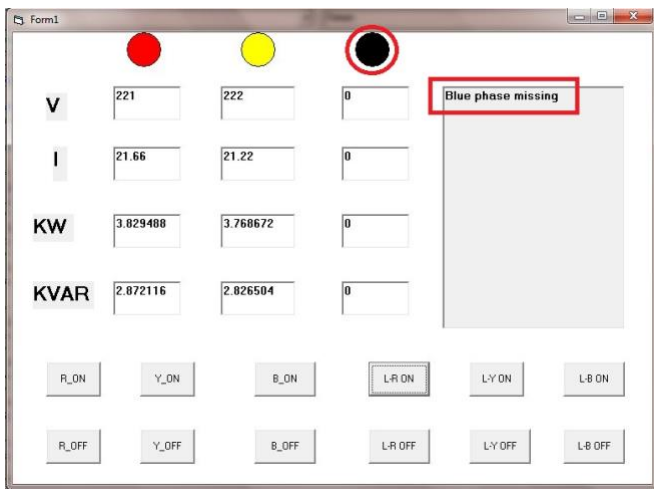
and the output load was analysed based on the load conditions at various levels, revealing different phase switching at different loads. Examples of how CSV data from the hardware is processed and sent to the computer via the RS232 interface are shown in Fig. 9. This data is then forwarded to the VB GUI interface. In this study, the system cut-off was simulated using selector switches, and the variation of load current was controlled with the help of potentiometers.

4.1. Situation 1 (Blue phase is disconnected)

The selector switch for the Blue-phase has been switched off to portray a situation where this phase gets cut off. Thus, the VB GUI turns the blue circle into black and gives a warning prompt 'Blue phase missing,' along with a voice announcement, as shown in Fig. 10.



(a)



(b)

Fig. 10. (a) The missing blue phase is indicated by switching off the selector switch on the hardware, and (b) the corresponding result is displayed in the VB GUI.

4.2. Situation 2 (Yellow phase is disconnected)

Similarly, the selector switch for the Yellow-phase has been switched off to portray a situation where this phase gets cut off; thereby, the VB GUI turns the yellow circle into black and gives a warning prompt 'Yellow phase missing,' along with a voice announcement, as shown in Fig. 11.

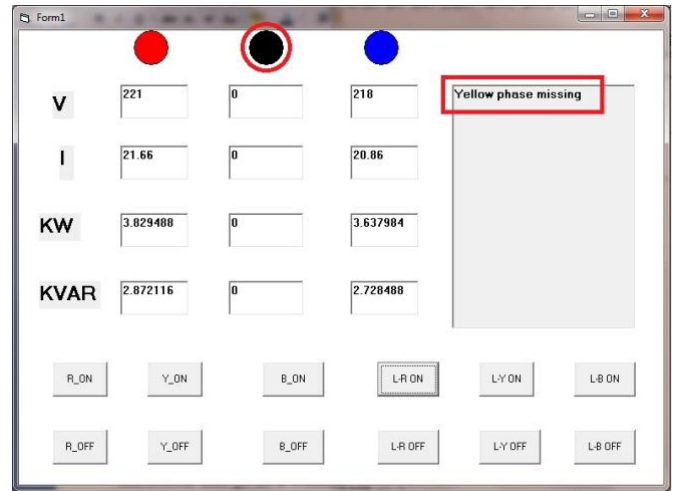


Fig. 11. When the Yellow phase is missing.

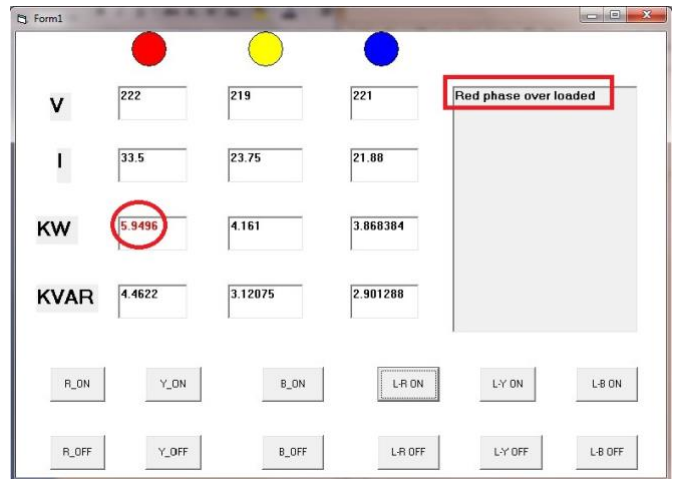


Fig. 12. When the Red phase is overloaded.

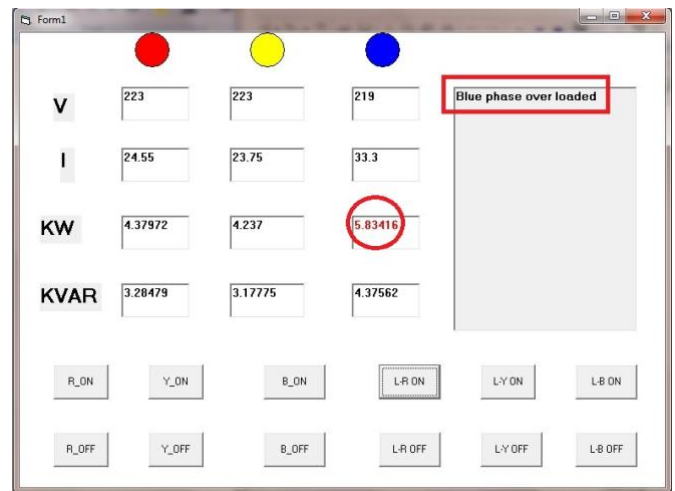


Fig. 13. When the Blue phase is overloaded.

4.4. Situation 4 (Blue phase in overload condition)

Fig. 13 shows that when the blue phase experiences an overload situation, the VB GUI displays the power rating in red and provides a warning prompt, "Blue phase overloaded," along with a voice announcement.

4.5. Situation 5 (More than one phase overloaded)

Fig. 14 shows that when the yellow and blue phases experience an overload situation, the VB GUI displays the power rating in red and provides a warning prompt, "Y and B phases overloaded," along with a voice announcement.

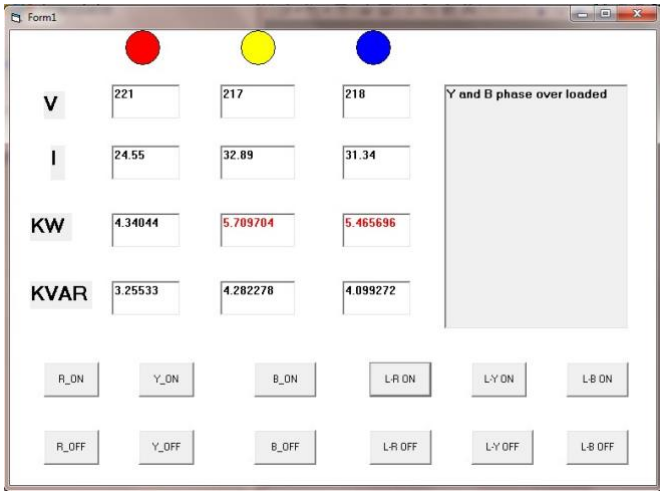


Fig. 14. Illustration of the situation when more than one phase is overloaded.

4.6. Situation 6 (VB GUI controlling the load)

In Fig. 15(a), the LR-ON button was pressed, which is reflected in the hardware shown in Fig. 15(b), where an additional load is connected to the red phase. Similarly, in Fig. 16(a), LR-OFF was used, resulting in Fig. 16(b), which shows the additional load being switched off. Fig. 15 illustrates the load connected to each phase, with the selector switches pressed to turn the load ON. Fig. 16 demonstrates the load being turned OFF from the GUI and how the operation is carried out in practice. The Arduino Uno detects load fluctuations and sends a signal to the quick-switching relay to connect the single full-house load to the least loaded phase of the three-phase LV network. No neutral current flows when the load varies from 0 to 500W on each phase. Instead, the load varies while measurements are collected at various points. There will be no neutral current flow within the mentioned fluctuation range, ensuring system stability. This hardware is designed to handle a load variation of 30A, but the proposed system also modifies it to increase its load variation rating to meet additional requirements.

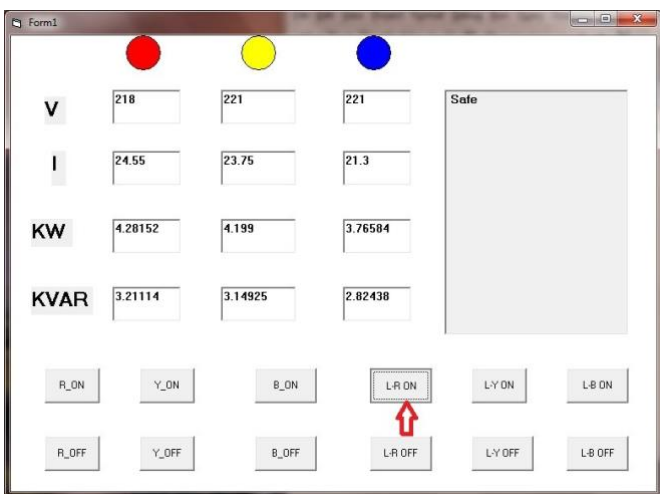


Fig. 15. (a) Additional load is connected to the Red phase by switching on the LR-ON button.

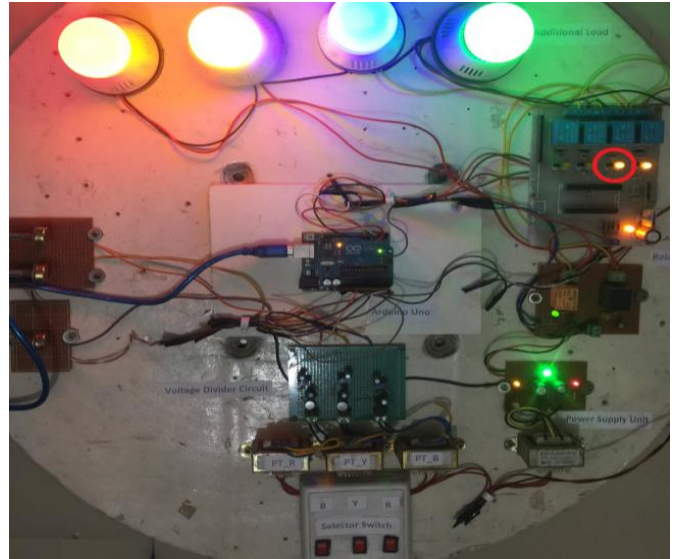


Fig. 15. (b) Turning on the bulb on the right side indicates that the additional load is connected to the Red phase.

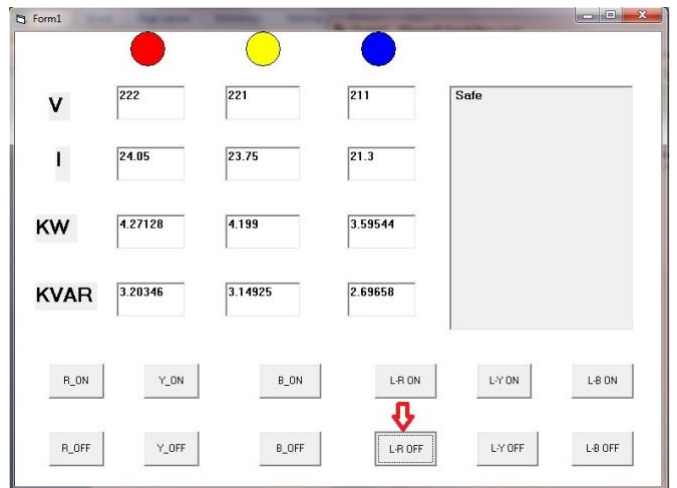


Fig. 16. (a) Additional load is disconnected from the Red phase by switching off the LR-OFF button.



Fig. 16. (b) Turning off the bulb on the right side indicates that the additional load has been disconnected from the Red phase.

4.7. Advantages

The proposed three-phase load-balancing system offers several key advantages over traditional methods. It provides real-time automated balancing, continuously monitoring and adjusting phase loads without manual intervention, improving efficiency and response times. Using Arduino Uno and a GUI for precise measurement and control, the system enhances accuracy by dynamically distributing loads to prevent phase overloading. This reduces issues such as voltage instability, energy losses, and neutral current flow, ensuring system stability. Additionally, the system enables cost-efficient load shifting, optimizing energy consumption and reducing power losses, which improves the efficiency of the distribution transformer. The user-friendly GUI provides real-time monitoring and control, offering immediate feedback on phase conditions and allowing for quick decision-making. By balancing loads across phases, the system minimizes energy losses and neutral current, a common issue in unbalanced systems. The prototype testing in Proteus and modular design allows for easy scalability, making it suitable for larger applications. Moreover, voice and visual alerts for phase disconnection or overload enhance safety, a crucial feature that traditional systems lack.

5. Conclusion

Load unbalancing can lead to issues with phase unbalancing. Automated three-phase load equalization offers a solution. This study describes a load balancing model for a smart low-tension feeder. The proposed model utilizes an Arduino to make decisions and operate according to specified preferences. Currently, load shifting is done manually, but the proposed system, which balances the three phases by monitoring electrical components, using control panels, and switching matrices, aims to eliminate labour and enhance precision. This benefits the electricity grid. Although the domestic load is a single phase connected to a three-phase distribution network, phase unbalancing occurs due to overloading one phase relative to the others. To address this issue, the distribution system must equalize the load across each phase. Achieving equitable sharing reduces energy losses, overload situations, and return current flow in the neutral of a three-phase system. The proposed technology, which involves a microcontroller and relay-based hardware, enables the implementation of an automated three-phase load-balancing system. Fast-switching relays are employed to shift the domestic load to the least loaded phase through the hardware installed on the incoming three-phase lines. By switching the relay ON/OFF, the entire home load is connected to the phase with the least load. Hardware and simulation results demonstrate the effectiveness of microcontroller and relay switching in reducing unbalancing in three-phase lines. Additionally, the system maintains voltage stability and control across all three phases.

References

[1] S. U. Haq, Bilal Arif, Asif Khan, and Junaid Ahmed. "Automatic three phase load balancing system by using fast switching relay in three phase distribution system."

In 2018 1st International Conference on Power, Energy and Smart Grid (ICPESG), pp. 1-6. IEEE, 2018.

- [2] M. O. Shakeel, S. A. Jaffar, M. F. Ali, and S. S. Zaidi, "LV three phase automatic load balancing system", 4th International Conference on Energy, Environment and Sustainable Development 2016 (EESD 2016).
- [3] F. K. Handhal and A. T. Rashid, "Load balancing in distribution system using heuristic search algorithm," 2018 International Conference on Advance of Sustainable Engineering and its Application (ICASEA), Wasit - Kut, Iraq, 2018, pp. 48-53, doi: 10.1109/ICASEA.2018.8370954..
- [4] L Cao, G Feng, X Cheng, L Wang, "Configuration of smart phase-swapping switches in low-voltage distribution systems based on sequenced participation indices." *Measurement and Control*. 2020;53(7-8):1159-1170. doi:10.1177/0020294020920899
- [5] VA Jimenez, ALE Will, DF Lizondo, "Phase reassignment for load balance in low-voltage distribution networks." *International Journal of Electrical Power & Energy Systems*. 2022 May 1;137:107691.
- [6] CH Lin, TT Ku, CS Li, CS Chen, "Optimal Phase Balancing in Electricity Distribution Feeders Using Mixed-Integer Linear Programming." *Sustainability*. 2023; 15(5):4473. <https://doi.org/10.3390/su15054473>
- [7] A Kaur and B Kaur, "Load balancing optimization based on hybrid Heuristic-Metaheuristic techniques in cloud environment." *Journal of King Saud University-Computer and Information Sciences*. 2022 Mar 1;34(3):813-24.
- [8] GA Ajenikoko, OEO Ajenikoko, A Adedoyin, BE Badmus and EA Lawal, "Application of genetic algorithm to network feeder reconfiguration in radial distribution system." *International journal of advanced scientific and technical research*. 2018 Jul;5(8):15-29.
- [9] R. Prananda, H. S. Dini and T. W. O. Putri, "Design of Load Balancing Method on Secondary Distribution Network Using Artificial Intelligence Based on Fuzzy Logic," 2021 3rd International Conference on High Voltage Engineering and Power Systems (ICHVEPS), Bandung, Indonesia, 2021, pp. 372-377, doi: 10.1109/ICHVEPS53178.2021.9600977.
- [10] W. Siti, A. Jimoh, and D. Nicolae, "Distribution network phase load balancing as a combinatorial optimization problem using fuzzy logic and Newton-Raphson", *ELSEVIER Electric Power Systems Research* Vol.81, No.5, pp.1079-1087, 2011.
- [11] C. Lin, C. Chen, H. Chuang, M. Huang, and C. Huang, "An expert system for three-phase balancing of distribution feeders", *IEEE Transactions on Power Systems*, Vol. 23, No. 3, 2008.
- [12] CI Ciontea and F Iov, "A Study of Load Imbalance Influence on Power Quality Assessment for

- Distribution Networks.” *Electricity*. 2021; 2(1):77-90. <https://doi.org/10.3390/electricity2010005>
- [13] Naumov, Igor, Sergey Podyachikh, Dmitri Ivanov, Alexander Tretyakov, and Andrey Bastron. "Analysis of unbalanced load low-voltage electrical networks operating modes." In *E3S Web of Conferences*, vol. 295, p. 02005. EDP Sciences, 2021.
- [14] Bina, M. Tavakoli, and A. Kashefi, "Three-phase unbalance of distribution systems: complementary analysis and experimental case study", *International Journal of Electrical Power & Energy Systems* 33.4: 817-826, 2011.
- [15] Rios, Miguel Angel, Juan Camilo Castano, Alejandro Garcés, and Alexander Molina-Cabrera. "Phase Balancing in Power Distribution Systems: A heuristic approach based on group-theory." In *2019 IEEE Milan PowerTech*, pp. 1-6. IEEE, 2019.
- [16] SR Khandker, DF Barnes and HA Samad, "Welfare impacts of rural electrification: a case study from Bangladesh." World Bank; 2009.
- [17] MS Board, "Designing sustainable off-grid rural electrification projects: principles and practices." World Bank: Washington, DC, USA; 2008.